Contribution ID: **114**

Type: **Poster**

Future developments of radiation tolerant sensors based on the MALTA architecture

Thursday, 22 September 2022 16:40 (20 minutes)

The planned MALTA3 DMAPS designed in the standard TowerJazz 180 nm Imaging process will implement the numerous modifications, as well as front-end changes in order to boost the charge collection efficiency after the targeted fluence of 1x1015 MeV neq/cm2. The effectiveness of these changes have been demonstrated in recent measurements with a small-scale mini-MALTA demonstrator chip. Proposed changes in the periphery of the MALTA3 sensor are listed and discussed, with an added focus on timing performance improvements (<1ns resolution) as well as research of the overall sensor architecture.

Summary (500 words)

Depleted Monolithic active-pixel sensors (DMAPS) present the next step in development of tracking detectors used in high-energy physics experiments. In order to meet the increasing spatial resolution targets of future experiments, a reduction of the pixel size will not be enough –multiple scattering of the charged particles will become the main limitation.

By integrating the sensor and its readout circuitry into the same silicon die, this effect is lessened through a smaller material budget of the system. Monolithic designs also benefit from reduced cost of manufacture, as the expensive bump-bonding step needed for hybrid sensors is not needed. The overall power consumption is decreased due to a smaller input electrode capacitance, contributing to the material budget reduction.

The MALTA sensors are a series of DMAPS manufactured in the TowerJazz TS18 Image Sensor Process, originally designed to match the Inner Tracker requirements of the ATLAS experiment for the High-Luminosity LHC. The targeted fluence of 1015 1 MeV neq/cm2 , and an efficiency of over 97.5% have been demonstrated with the recent mini-MALTA split 7 chip, reaching the requirement set by the 5th layer of the ITk for the Phase-II upgrade of ATLAS This result is attributed to process modifications and front-end amplifier upgrades implemented over the years.

All of the MALTA sensors feature 36.4 um pixels, arranged in a novel asynchronous matrix.
By omitting a fast global clock, the power consumption is increased significantly. However, such a matrix can only transmit the spatial information of the passing particle –the hit timing is performed either off-chip (MALTA) or within the on-chip periphery (mini-MALTA).
By sharing the timing circuitry over a large number of pixels, a very high resolution is attainable with a reduced area and power penalty.

Due to the demonstrated efficiency and radiation tolerance of previous chips, the MALTA3 sensor will focus on architecture level modifications, and pushing the timing performance to the limit of the 180nm TowerJazz fabrication process. The on-chip timing synchronization concept first presented in the mini-MALTA chip will be expanded to a full reticle size (768x512 pixels). Previously implemented merging structures used for chip-to-chip data transmission will be redesigned as they cannot be combined with the new synchronous periphery. The timing synchronization module will be upgraded in order to reach a sub nanosecond resolution, while still being able to cope with hit rates up to 100MHz/cm2.
Changes to the calibration structures, as well as secondary chip functions will be discussed as well.

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Session Classification: Thursday posters session

Track Classification: ASIC